Behaviour of Accommodation and Convergence under the Conflicted Stimuli

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Abstract. Visual fatigue caused by viewing stereoscopic images are often attributed to underlying discrepancy between accommodative and convergence stimuli included in the image. However no theory on the mechanism of fatigue from the discrepancy nor precise behaviours of accommodation and convergence under the conflicted stimuli has been known. Our recent attempts to analyse the behaviours besides the control system of these functions will be presented with special interest in the spatial structure of the images in the frequency domain.

Introduction

Many people prefer 3-dimensional images. But the depth perception can be obtained from the 2-dimensional images. Depth perception in human vision relies on a number of cues that are either psychological or physiological in origin. Psychological cues include: perspective, overlap, air perspective, shadow, apparent size, texture, etc. Physiological cues include: binocular parallax and motion parallax. However, depth perception can still be experienced when all physiological cues are missing, otherwise depth would never be perceived while viewing pictures and paintings. In motion images depth is perceived, even when the viewer is not moving, due to a type of motion parallax that arises from camera movement. Three-dimensional computer graphics (3D-CGs) rely mainly on this physiological cue in addition to psychological ones.

Binocular parallax refers in general to image difference, while binocular disparity refers to retinal image differences, due to the small spatial displacement between the left and right eyes, which requires convergence to fuse the image at a particular distance. Physiologically, binocular disparity evokes a sense of depth. Using 2 2-D images including binocular disparity we cane get strong depth sensation. This is called as stereoscopic image. Though various projects are underway to create true 3-D images, an inexpensive system capable of executing this task remains to be developed. To date, stereoscopic images have only been possible to realize easily. One problem is that discrepancy between accommodative and vergence stimuli is common in such images because accommodation should respond only to the screen/image position, but disparity of the two images for both eyes, vergence stimulus, varies with time. This conflict can be highly stressful for the visual system.

Sometimes we experience difficulties to fuse binocular images. However, the figure changes its form depending on the contents of the image. For example, we cannot fuse the disparities near the fixating position but we can easily fuse the disparities presented at peripheral visual fieald.

Background: Accommodation and Convergence

Usually, accommodation and convergence responses are closely related. However, they may also differ depending on the stimuli. If the discrepancy is small, the two functions respond correctly. The stimuli and responses are unnatural, and result in visual stress according to the accepted theory. A brief review of the characteristics of accommodation and vergence is presented in this section.

Accommodation has limits for both near and distant viewing. They are called as ‘near point of accommodation’ and ‘far point of accommodation’. Displacement of the far point of accommodation from infinity is known as ‘ametropia’. The near point of accommodation increases due to aging. The resulting subjective feeling of focal inability experienced in daily life is known as ‘presbyopia’. When accommodation is completely relaxed, it adapts to the far point. However, when no accommodative stimulus is available, as in darkness or an empty field, accommodation assumes an intermediate position between the far and near points. This is known as ‘tonic accommodation’. Tonic accommodation is affected by visual fatigue. Visual targets further or closer than the tonic accommodative point do not induce precise accommodation and errors are biased toward the tonic position. Such errors are known as ‘accommodative lead’ or ‘accommodative lag’. After accommodating to a different position from the tonic accommodative point, tonic position shifts from the initial position. This is known as ‘accommodative adaptation’.

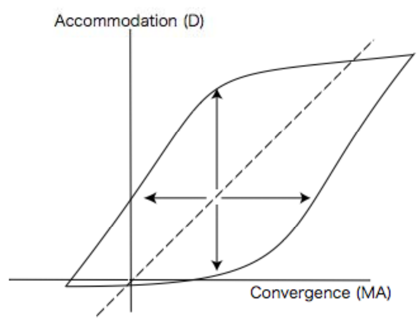

Figure 1. Area where the combination of accommodation and convergence stimuli causes neither blurred nor double vision. The broken line shows the ‘Donders line’.

Similarly, the convergence process is bounded by the fusion limit, which usually displays a wider range than the accommodation range, particularly in the aged. This is because the convergence function does not diminish with age, as the accommodative function does. The error in convergence, known as ‘fixation disparity’, is similar to the accommodative lag or lead. It is small and changes with distance in a complex manner with large inter-individual variations. Vergence state under the no-stimulus condition is known as ‘phoria’. The change in phoria, after fixation at a certain distance, is known as ‘phoria adaptation’, ‘vergence adaptation’, or ‘prism adaptation’.

Comparison between accommodation and convergence is based on a scale given in units of reciprocal meters (1/m). Diopters (D) for accommodation and meter angle (MA) for convergence are units based on this principle. Convergence and accommodation cannot be fully independent of each other. The limitations of both functions are shown in Figure 1. This graph shows a combination of accommodative and convergence stimuli. When viewing this graph horizontally, the convergence limit is calculated, while assuming that the accommodative stimulus remains fixed. The resulting area, where the combining of accommodation and convergence stimuli causes neither blurred nor double vision, shows very large individual differences, which depend on phoria, ametropia and its correction, and the degree of presbyopia.

An accommodative response to a stimulus, in the absence of a stimulus for convergence, such as when one eye is occluded, can elicit convergence responses known as ‘accommodative convergence’. The ratio of accommodative convergence to the unit accommodation (‘AC/A ratio’) shows the intensity of accommodative convergence. Silarly, ‘convergence accommodation’, and the ratio of that to the unit convergence ('CA/C ratio'), can also be defined. AC/A and CA/C ratios are changed by the adaptation of accommodation and vergence. However, it is not easy to present a stimulus to convergence without eliciting accommodation. One solution is a use of highly low-pass filtered image (Tsuetaki and Schor, 1987). It hardly evokes accommodative responses.

Difficulty to View Stereoscopic Image

Simultaneous measurements of accommodation and convergence when viewing stereoscopic images were carried out (Ukai and Kato, 2002). Stereoscopic images were presented on a parallax-barrier LCD display. Accommodative responses were measured using a modified video refractor. Results support to the theory that the cause of visual fatigue is the discrepancy in accommodation and vergence. Recordings revealed unstable accommodative responses as shown in Figure 2, and suggest difficulty in controlling accommodation. Accommodative responses mark the equilibrium point between convergence-driven accommodation that pulls toward a position closer to the viewer, and defocus-driven accommodation that pushes it to stay at the screen position.

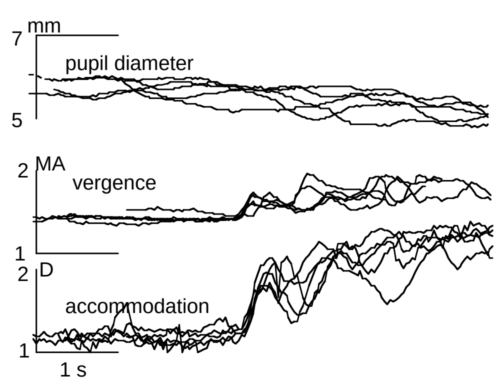

Figure 2. An example of actual recording of near triad (pupil, convergence and accommodation) from a viewer of stereoscopic image after Ukai and Kato (2002) with permission by the publisher.

Static Responses of Accommodation to Stereoscopic Stimuli

In order to support the explanation by Ukai and Kato (2002), the demand of defocus-driven accommodation was reduced by blurring, i.e., by reducing the higher spatial frequency components of the visual target.

The remaining low spatial frequency components were less affected by defocus, and inaccurate accommodation was permitted. Figure 3 shows an accommodative response that varied with target blurring while viewing stereoscopic images. This Figure is schematic drawing of the results obtained by Okada et al. (2006). When the target is clear, the accommodative response closed to the screen position while the convergence response is approximately at the pop-up position (left of the Figure 3). In this state the discrepancy of the accommodation with convergence is large. In contrast the accommodative response is determined by the convergence and both are close to the convergence stimuli (right of the Figure 3). The precise refraction unit was used instead of video refraction unit, and then simultaneous recording of the convergence was not easy.

The quality of stereoscopic display images is improving continuously, a desirable development. However, when stereoscopic systems were derived, their use increased the occurence of discrepancy between accommodation and convergence, which has lead to possibly increased visual fatigue.

Overshoot Responses Observed in

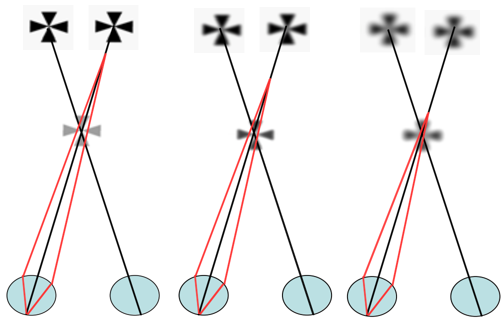

Figure 3. Accommodative responses when viewing stereoscopic images depend on the target blur. Accommodative responses to the stereoscopic images varied by the target blur.

Dynamic Accommodative Responses

Using video refraction again, accommodative and convergence dynamic responses were measured to stepped changes in convergence stimuli with unchanged accommodative stimuli (conflicting stereoscopic image) and compared with responses to non-conflicting target stimuli (Torii *et al.*, 2007). Three targets were used that varied in their spatial frequency components as used by Okada *et al.* (2006). An accommodative transient overshoot as shown in Figure 4 was evident in 4 out of 7 subjects for only conflicting stimuli. Convergence dynamic responses were smoothto all stimulus in all subjects

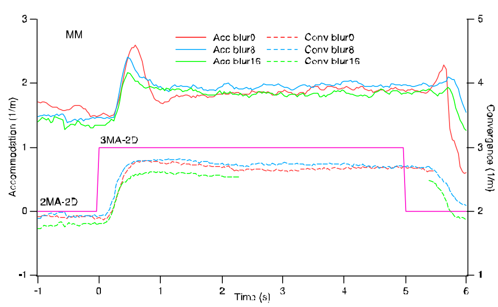

Figure 4. Typical accommodative and convergence responses for one subject in conflicting stereoscopic condition. Each waveform is an average of 5 trials. Solid lines: Accommodation response, Broken lines: Convergence responses.

unless fusional difficulty did occur. One subject showed accommodative and convergence oscillation probably due to difficulty in fusing the stereoscopic target when it had a higher spatial component, however, this oscillation diminished when the target was spatial low-pass filtered. We hypothesize that transient responses to step stimuli is initiated by convergence-driven accommodation and subsequently followed by slower fine-control of accommodation modulated by the amount of blur. Inter-individual differences in convergence-driven accommodation may also be a factor to consider. For stereoscopic stimuli, it is proposed that the increase in blur immediately after the onset of the accommodative response inhibits cessation of the response.

CA/C Ratio and Inter-individual Differences in Dynamic Responses

As mentioned above, some subjects show overshoot in accommodative responses to a step change in stereoscopic target, but others do not. The accommodative overshoot may occur as a result of influences from convergence-induced accommodation, which is the first phase of the accommodative response, followed by blur-induced accommodation. The hypothesis that the overshoot appears when an individual's CA/C ratio is high was examined (Fukushima *et al.*, 2007). CA/C and AC/A ratios were measured respectively by blurring stimulus and by occluding one eye. The results showed that CA/C and AC/A ratios are negatively correlated as shown previously (Schor, 1988) and that amplitude of the overshoot is larger in subjects with higher CA/C ratios as shown in Figure 5. We conclude that the transient overshoot in accommodative responses is caused by excess convergence accommodation.

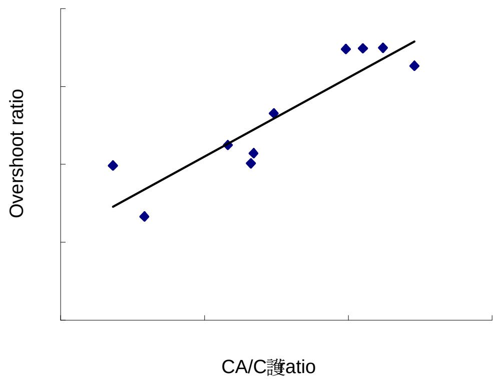

Figure 5. Comparison of overshoot with CA/C ratio. Each plot represents each subject. Individfuals with higher CA/C ratio has larger overshoot.

Conclusion

By a series of analysis of accommodative and convergence responses to the stereoscopic stimuli, we have clarified that the variety of responses in accommodation is important. The responses depend on the target spatial characteristics, CA/C ratio of the viewer. Fusional limit, phoria, range of the accommodation of the viewer may also affect accommodative responses and convergence responses, and affects probably visual fatigue induced by stereoscopic images, although we have not examined such variables so far. Pupillary size of the viewer which determines torelance to the accommodative error and the luminance of the image which determines the size of pupil are also factors of fusional limit.

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